The Servo Flap
Controlled Rotor

Wrote for the Helicopter History Site by **Kiran Singh**

Helicopter design has come a long way from the days of Breguet, Pescara, Cierva and even since Sikorsky 's first successful vertical lift machine. Along the way there have been attempts to design the machine in order to :
increase maximum forward speed
improve the streamlining of the machine i.e. reduce drag and hence the power required
reduce the vibrations in the helicopter
improve the stability and control characteristics
These are some key issues associated with a conventional helicopter. The servo-flap is one method that has been found to be of use in tackling some of these problems.

What is the Servo Flap and How Does it Work?

The servo flap is a small airfoil located at about 75 percent span of the rotor blade, situated on the trailing edge of each rotor blade. These flaps are controlled by the pilot through push-pull control rods and their function is similar to that of an elevator on fixed wing airplanes.
Moving the trailing edge of the flap upward moves the leading edge of the main rotor blade up. This increases the rotor pitch or the lift in very much the same manner as the elevator, on a fixed wing aircraft, changes the angle of attack on the wing. Thus the helicopter pilot can cause the angle of attack of the flap to increase or decrease in pitch, causing the helicopter to alternately dive or climb.
In the conventional rotor design the pitch of the rotor blade is varied by the introduction of a hinge near the root of the blade, which can rotate the blade about the pitch change axis. As could be imagined, the moment arm near the root being smaller than at the three-quarter radius of the blade as it is for the servo-flap – the forces required to produce the pitching moment will be much larger. The servo-flap does the work of more complex and heavy hydraulic control systems. Hence for this system the total control forces would be much lower because the work to move the blade happens right where lift is being generated. An accompanying advantage is the fact that this dampens out the vibrations that are generated in the blade due to varying lift and eliminates the transmission of these vibrations to the airframe. Vibrations being the cause for reduced life of the hub and blades and accompanying parts, due to fatigue, is now no longer a factor to contend with. This is what gives the helicopter blade and the hub in such a helicopter its well-touted infinite life, which essentially implies that the life of the rotor blade is equivalent to the life of the airframe. Consider this with the fact that for a conventional helicopter the rotor blade and hub has a far shorter serviceable life than the airframe.
Furthermore since the servo flap uses energy drawn from the air-stream to pitch the blades up and down, the control forces need only be high enough to deflect the small servo flaps, thereby reducing the complexity of the control mechanism at the blade hub significantly. Also note the additional stability effect that is factored into such a system where the servo flap by contributing to additional rotational and flapping inertia, provides the system with angle of attack stability as also acts as a gust alleviation device. Thereby justifying the analogy between the servo flap and the elevator in a fixed wing airplane. So in the event of an engine failure, the servo flap responds automatically to increased angle of attack caused by the change in airflow

through the rotor and decreasing rotor RPM. Although the pilot still has to lower collective to stabilize the autorotational descent, the servo flap provides the pilot additional reaction time before rotor RPM decays too low. An accompanying advantage is the ability of the system to provide for in-flight rotor blade tracking. This is made possible by an electric actuator in each tab control, which allows tracking in flight and on the ground.

The Conception of the Servo-Flap

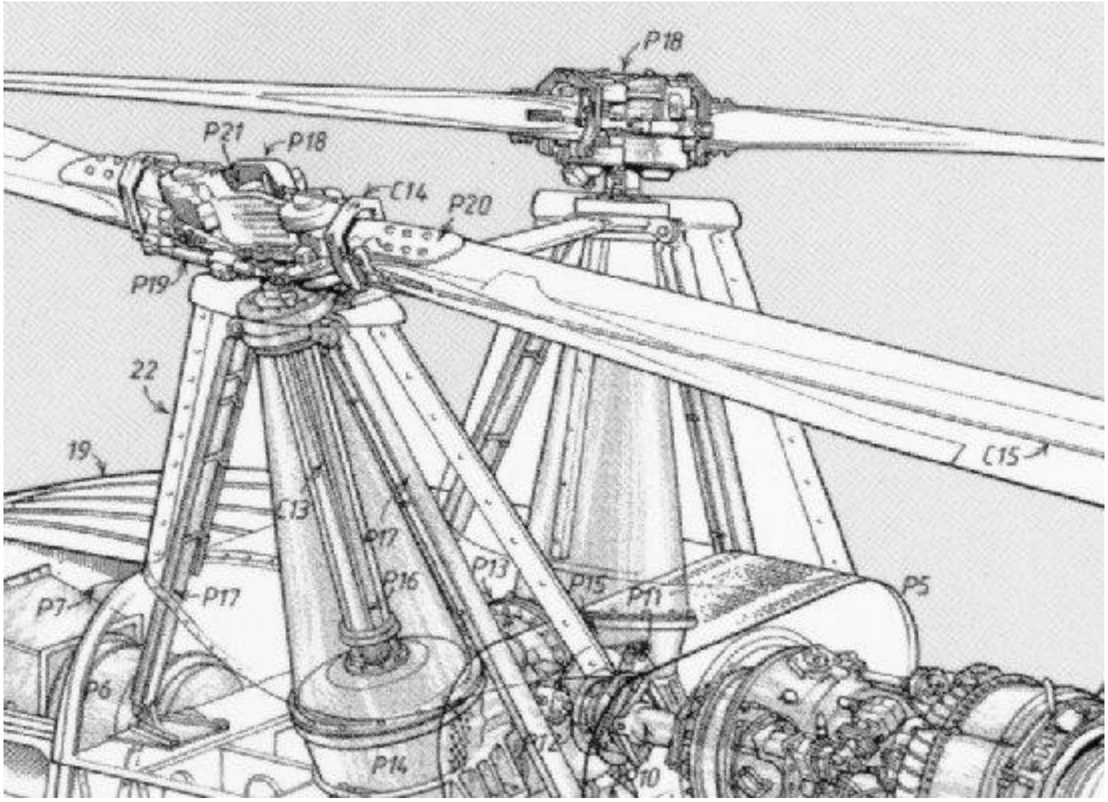
The concept of trailing edge flap for active control essentially originated with Raul Pescara 's helicopter of 1922, which featured plain flaps for 1/rev blade pitch control.
Corradino D'Ascanio 's conception of the servo flap as a control mechanism and its application in his co-axial helicopter design later became an integral design feature of the helicopters designed by Charles Kaman. However while D'Ascanio applied servo tabs for collective and cyclic pitch control, Charles Kaman applied the servo tab for rotor pitch changes as well, thereby making the blade twist rather than rotating the blade with the help of a hinge at the root. This simplified the rotor hub significantly. The first helicopter that Charles Kaman designed was the K-125 in 1947, and the servo-flap was a primary design feature in that. Since then servo flaps have been the method of pitch control in helicopters designed by the Kaman Aerospace Company. Interestingly the conception of pitch control took place at Sikorsky.
In 1940, Charles Kaman was working at Hamilton Standard, a division of United Aircraft in East Hartford Connecticut, on propellers and later on the aerodynamic design of the Sikorsky VS-300. Working on the problem of stability and control, he started analyzing ways to overcome this. His initial attempts at providing a hinged surface similar to an aileron in fixed wing aircraft had to be abandoned when he realized the inherent flaw in his design. The assumption that the rotor blade was rigid was physically being violated by the fact that the blade was long and flexible and was unable to contain the lift generated by the lowered flap. As a result the blade twisted down each time the flap was deflected and remained that way until the flap was raised. He abandoned his attempt to reproduce the ailerons on helicopters and started work on the servo flap.
While most helicopters control blade pitch by using mechanical force at the rotor hub, he found that servo flaps could change pitch by utilizing aerodynamic forces acting on the blade itself. By eliminating the pitch control mechanism at the hub, the hub could be simplified significantly since the smaller surface area of the servo flap required lower operating forces. The two flaps he designed were about the same size and looked much alike and Kaman bolted the servo to brackets, which extended from the front and back of the blade. The servo flaps separation from the blade was the key difference. After experimenting with different flap configurations he settled on placing the device at the trailing edge of the blade, at the three-quarter-radius point. The angle of the servo flap, controlled by the pilot twisted the flexible blade into the desired blade pitch, eliminating the need to change pitch from the rotor hub and by compensating for each blades' inconsistencies, the servos cut down on vibrations. When Kaman tried to get upper management at Sikorsky interested in the servo flap, he was given an interesting reply. " Charlie, we have our own inventor at United Aircraft. His name is Igor Sikorsky. We don't need another one. Soon after Kaman left the company and with $2000 and his own invention, he started Kaman Aerospace Corp.

The Configuration of a Helicopter Using Servo Flaps

A good way to understand the advantages of this system is to consider a helicopter that is designed applying this technology. The Kaman K-Max K1200 is a good study in this area.

Type: Single seater, external lift intermeshing rotor helicopter and military multi-mission intermeshing rotor aircraft (MMIRA).
Design Features: Kaman intermeshing rotor ensures all the engine power is produced for lift, in addition rotor disc loading is very low – which provides greater lifting capability per helicopter. It has Kaman intermeshing two bladed contra-rotation rotors with separate inclined shafts emerging from a common transmission. Lifting power is increased because induced drag and downwash of the intermeshing rotor system is reduced and power drain of the tail rotor is eliminated. The blade centerline is offset from the hub and there is a single drag bearing with drag damper. Small trailing edge tabs set the blade pitch, light control loads and low feedback eliminate the need for powerful pitch change rods and levers and hydraulic powered controls, all bending and twisting is caused by pitch change accommodated by blade flexing. The engine is mounted horizontally behind the transmission. Minimum overhaul life for all parts except the engine is 2400 hrs.
Flying Controls: Blade angle of attack is controlled by trailing edge tabs and light control linkages, avoiding the need for hydraulic power. Normal powered flight turns at or near hover are effected by applying differential torque to the rotors by means of differential collective pitch commanded from the foot pedals. Intermeshing rotors cause pronounced pitch attitude change in response to collective pitch change, The K-Max tailplane is connected to the collective to alleviate this problem as well as to reduce blade stresses and to produce touchdown and lift off in level attitude.
Structure: Light alloy airframe, composite main rotor blades and servo flaps. Tail assembly weighs 36.3 kg and can be quickly removed by two people. Karon bearings, Kaflex couplings are used which require no lubrication and zero maintenance.
Power Plant: One 1343 KW (1800 SHP) Textron Lycoming T53-17A turboshaft. Since the K-Max only requires 1160SHP to operate at the maximum gross weight on a standard day at SL, there is plenty of power for hot and high days.

The resulting helicopter can carry more payload for fuel used, maintained with minimum power and fewer parts are required to maintain and track. It can move more weight reliably with less support and lower operating cost. The intermeshing rotor configuration makes the K-Max one of the quietest helicopters. (4dB lower than the FAA maximum dB level of 87 dB.)



Comparison of the Rotor System with a Conventional Rotor Configuration

The servo flap mechanism in essence operates the flap on the trailing edge of the rotor blade in order to change the pitch of the blade. Mechanical linkages from the rotor head run through the blade to this small flap and changing its pitch in much the same manner as that for conventional rotors. Flap and lag hinges are present as in the conventional helicopter blade. This mechanism is different in that it does not require any hydraulics between the pilot and pitch change mechanism because the moment arm is so large that suitable mechanisms can be designed such that pilot effort is low. The collective and cyclic pitch system differs in manner of operation from the conventional configuration due to the use of servo flaps.

Collective System: The primary components in this system are the collective stick, throttle and push-pull control rods connected to the servo flaps through the azimuth assembly. The prime function of the collective system is to control the pitch of all the rotors. Raising the collective lever causes the servo flap trailing edge on each rotor blade to move upward, increasing the pitch on all four blades, collectively and equally. This increases the lift causing the helicopter to rise. Conversely, lowering the collective decreases lift and the helicopter descends. Engine power is synchronized automatically with these pitch changes to hold the RPM constant. In a synchropter like the K-Max, the collective is mechanically linked to the moving elevators on the tail boom. Up collective results in the elevator leading edge to move up. This further reduces the pilot workload by minimizing pitch attitude changes with collective lever movement.

Cyclic system: The cyclic control system consists of the cyclic control stick and push pull rods connected through the azimuth assembly to the servo flaps. Movement of the cyclic stick in a given direction causes one - or for the intermeshing system - both rotors to tilt and fly the helicopter in the same direction and at speed relative to the amount of stick movement. When the cyclic stick is moved forward one (or both) the rotors tilt forward equally. The same is true of the aft cyclic stick movement. In the case of the intermeshing system the application of lateral cyclic does not result in both the rotors tilting sideways the same amount as the fore and aft movement. Moving the cyclic to the left cause the left rotor to tilt to the left in proportion to the amount of left control input and conversely for moving to the right. However in the synchropter the directional control system analysis is a bit more involved and will not be included here, as it does not directly allude to the topic at hand.

In comparison the conventional rotor-hub design is fairly complicated. The blade in such a design rotates in pitch about a bearing, aligned in a radial direction, which can be a roller bearing stack or a composite flexure. The pitch is applied via an arm projecting forwards from the pitch bearing housing known as the pitch horn. The pitch horn is connected to its own individual track rod by a swivel bearing and vertical movement of the track rod will cause the change in blade pitch angle. The lower end of the track rod is connected to a spider or rotating star, which is constrained to rotate with the rotor. A movement of the spider in a direction parallel to the rotor shaft will cause all the blades to rotate in pitch by the same amount, have the same pitch angle, and hence effect a change in collective pitch.
If the spider center maintains its location relative to the rotor shaft but its plane tilts, then it can be seen that as the blade rotates around the shaft as the rotor turns, the spider arm moves up and down once per rotor revolution. That is the blade pitch angle changes once per revolution and cyclic pitch is achieved. The pilot controls must therefore be able to control the spider's location and orientation with the added complication of the spider itself rotating both the shaft. The majority of the helicopters achieve this using a swash plate. This is essentially a flat plate joined to the spider such that they remain locked together in the same plane. The swash plate and spider combination slides up and down the rotor shaft and tilts relative to its common center. The swash plate is held stationary relative to the fuselage and its position and orientation is determined by three actuators, or jacks connecting it to the top of the fuselage or main rotor gearbox casing. The pilot's controls alter the strokes of the actuator which position the swash plate but rotates with the rotor and its position determines the collective and cyclic pitch angles. If the actuators move in unison the swash plate and spider maintain any tilt but slide along the rotor shaft and collective pitch is adjusted. If the actuators move unequally then the rotation plane of the swash plate and spider combination is altered and cyclic pitch is achieved.
As can be deduced from the description the conventional hub design is very complicated. Compare this with the rotor hub for a servo-flap configuration. Evidently the use of the servo flap simplifies matters far more than can be conceived. By far the most notable feature in this system is in the simplicity it provides to the rotor hub. Consider the fact that the typical weight of a main rotor blade would be around 200 lbs. while the weight of a servo-flap is around 6 lbs. Inevitably the amount of force required to operate the servo flap is far less. The servo flap hence obviates the need for the cumbersome design of conventional rotor hubs by getting rid of pitch change bearings and heavy hydraulics required to operate those bearings at the root. In addition the reduction in drag by the removal of many components in the hub is of tremendous advantage in streamlining the helicopter.

In Conclusion

As can be gathered from this analysis, the servo flap provides the whole helicopter with more stability with regard to angle of attack than other rotor control systems. It is easier to give wider margins for rotor blade flutter and it reduces the requirements for an AFCS to give good handling characteristics especially in gusts. It is lighter than other systems and needs no hydraulics, yet it gives better rotational inertia, which is important for good autorotational characteristics.
The servo flap is extremely simple in concept and execution yet very effective in control. The reasons for its application in helicopter design being limited to exactly one company are rather hard to comprehend, nevertheless should not be attributed to flaws in the system.